1. **Principal Investigator: Anthony D. Del Genio, NASA Goddard Institute for Space Studies**

2. **Title of Interagency Agreement: ARM Analysis of Optical Thickness for Low Clouds and Cumulus Anvil Clouds**

3. **Scientific Goals of Interagency Agreement:**

The broad range of uncertainty in IPCC estimates of the global climate sensitivity (1.5-4.5 C), which has not narrowed since the original 1979 estimate, is due in large measure to our inadequate understanding of the factors responsible for cloud optical thickness feedbacks. Previous research under this Interagency Agreement has used Atmospheric Radiation Measurement (ARM) Program data from the Southern Great Plains (SGP) to identify the physics controlling the temperature dependence of optical thickness for low clouds over midlatitude land. However, satellite and GCM analyses suggest that this feedback might be different in the tropics and polar regions. Furthermore, there is no reason to anticipate that high-level cloud optical properties will behave in the same fashion as low-level clouds. We propose to use newly available data sets from all three ARM sites to expand our understanding of optical thickness feedback to other climate regimes and to other cloud types. Forcing and validation data sets from Single Column Model (SCM) IOPs will be used to composite cloud properties in different phases of baroclinic and convective weather systems and thus to separate weather-associated variance from intrinsic temperature dependence. In addition to optical thickness itself, the data sets will be analyzed to constrain the causes of the transition from liquid to ice in clouds. The GISS SCM's ability to reproduce the observed variations of optical thickness and cloud phase will be tested, and modifications to its cloud parameterization will be made as necessary. Original and revised versions of the parameterization will be evaluated in the 3-D GISS GCM to determine whether model changes increase agreement with global satellite data sets. Finally, an equilibrium $2xCO_2$ simulation will be conducted with the revised version of the model to determine the effects of the changes on climate sensitivity.

4. **Accomplishments**

- Statistics of more than 24,000 tropical convective storms have been compiled from satellite data. These show characteristic differences between the relative proportions of small and large ice particles in land and ocean storms that can potentially help characterize the nature of convection at the ARM TWP Manus and Nauru sites.

- For one case of a mesoscale convective system that passed over Manus coincident with a TRMM satellite overflight, ice water contents parameterized from the satellite radar reflectivity profile and input to a radiative transfer code give predicted surface radiative fluxes similar to those observed by ARM instruments.

- GISS SCM simulations of the highly convective Summer 1997 SGP IOP produce downdraft mass fluxes weaker than the consensus from CRMs but closer to the CRM results than other SCMs.

5. Progress and Accomplishments During Last 12 Months:

a.) Microphysical and radiative properties of cumulus anvil clouds

In the GISS GCM, climate changes in the cover and optical thickness of cumulus anvil clouds can make the difference between strongly positive and weakly negative global cloud feedback. The anvil properties in turn are controlled by vertical transport and detrainment of convective condensate, a difficult process to parameterize. We therefore seek observational constraints on the properties of these anvils as a starting point for parameterization improvements.

We have used a clustering algorithm to compile statistics of the microphysical and radiative properties of the clouds associated with precipitating tropical convective systems. Precipitating storms are identified from satellite passive microwave radiances, using an algorithm of Kummerow and Tao. A database of predicted 4-channel microwave radiances from cloud resolving model simulations is then used to identify vertical profiles of cloud liquid, cloud ice, precipitating liquid, and precipitating ice that are consistent with the observed radiances. We have identified more than 24,000 tropical storms using this algorithm. We segregate storms by size and underlying surface type. We also use coincident lightning data as an index of convection strength.

Our findings are as follows: (1) Small storms, i.e., isolated cells or groups of cells with no anvil, are much more numerous than the mesoscale clusters emphasized in most previous field experiments (although the latter are of comparable overall radiative importance due to their great areal extent); (2) Precipitation-size particles dominate the ice water content of all types of storms; (3) Ocean storms have significantly more ice at small particle sizes than do land storms, while land storms have more precipitation-size ice; (4) Large storms generally have greater ice content than small storms, and strong storms have more ice than weak storms. Assuming reasonable particle sizes for cloud and precipitating ice as sampled by aircraft, we estimate that the cloud ice and precipitating ice contribute equally to anvil optical thickness for ocean storms, but only precipitating ice matters radiatively for continental storms. The next step is to verify the implied radiative differences using coincident CERES data.

The above analysis suggests a means of characterizing convection over the ARM TWP Manus and Nauru sites as more continental or maritime in character. In order to identify the most likely time periods for deep convection at the TWP sites, we have used long-term surface measurements of downwelling total, direct and diffuse solar fluxes, along with Long's clear-sky flux calculation technique, to calculate time series of surface shortwave cloud forcing and verify the previous impression of Mather et al. that convection is preferred during the active phase of the MJO. Using these time periods as a guide, we have inspected visible satellite imagery of Manus and Nauru, IR brightness temperatures obtained from the ARM Experiment Center, rain gauge data, and the previously determined surface shortwave cloud forcing to detect the passage of convective systems over the TWP sites. Thus far we have identified 13 such systems that passed over Manus at a time of simultaneous overflight by the TRMM satellite. The combination of ARM and TRMM data for these storms offers us the best opportunity to describe the 3-D microphysical and radiative vertical structure of these storms.

We are currently testing several techniques to derive consistent microphysical and radiative properties. Following Jensen (2000), we use the TRMM precipitation radar and a Z- IWC parameterization to derive IWC profiles for the region of the anvil detected by the radar, and assume a particle size and number concentration consistent with results of Churchill from the highest radar echo altitude to the IR cloud top, and input these to a radiative transfer model. As an alternative approach, we bypass IWC and use a Z-optical thickness parameterization of Churchill. Finally, we use the cloud/precipitation ice profiles from the Kummerow-Tao CRM-based passive microwave retrieval as a third input to the radiative transfer model. The first technique has been applied to the case of a mesoscale cluster passing over Manus on 12/3/98 with promising initial comparisons between calculated and observed surface radiative fluxes.

Finally, we are exploring the representativeness of the ARM Manus and Nauru sites by assembling a database of GMS IR brightness temperatures (obtained from the ARM external data center) over Manus, Nauru, and several other tropical west Pacific locations.

b.) Single column modeling

Development of the GISS SCM was completed, and the model was applied to the Summer 1997 SCM IOP. The model is based on the physics of a recent version of the GISS GCM that runs at 2 x 2.5 degree resolution with 18 vertical levels. When run continuously through the 29-day IOP, the SCM's temperature and moisture errors are comparable in magnitude to most other SCMs participating in ARM. It is our belief, however, that this is not the most fruitful way to use the SCM, because (1) such long runs are subject to the possible non- deterministic behavior demonstrated by Hack and Pedretti, and (2) accumulating errors in the thermodynamic structure make comparisons of parameterized cloud properties to ARM CWG cloud value-added products for the IOP periods moot. Thus, we have opted to run the SCM as a series of 24-hour predictions, restoring the model to the observed thermodynamic structure at the start of each day. To explore parameterization space, we run large ensembles of IOP simulations in which we systematically vary several important but uncertain parameters.

Since the Summer 1997 IOP was dominated by a few deep convective events at the SGP, we have tested the sensitivity of our simulation to the adjustment-to-equilibrium time of the cumulus updraft mass flux and the strength of the convective downdraft mass flux. The nominal SCM uses an adjustment time of 1 hour and a downdraft 1/3 the strength of the corresponding updraft. This run produces a vertical profile of net cloud mass flux that is closer to that simulated by cloud-resolving models than are other SCMs. Nonetheless, the downdraft mass flux of the SCM is underestimated relative to all the CRMs. An ensemble of 100 SCM runs that systematically varies the adjustment time and downdraft strength suggests that a somewhat longer adjustment time and stronger downdraft do indeed optimize column temperature and moisture errors. However, consistent moist biases in the planetary boundary layer remain, even during time periods devoid of convection and almost devoid of any cloud. We are currently exploring whether the ARM-estimated moisture budget is balanced; if it is not, we will reduce the ARM-derived latent heat fluxes to establish such a balance and drive the SCM with the modified surface fluxes.

6. Figures:

PI: Anthony Del Genio, NASA/GISS, FY2000. (Figure courtesy of Shaocheng Xie) Convective downdraft mass flux profiles simulated by the GISS SCM (brown curve) and other SCMs for three convectively disturbed periods during the Summer 1997 SGP SCM IOP. For comparison, the mean downdraft mass flux produced by 7 CRMs is also given (dashed black curve).

7. Refereed publications submitted or published during 1999-00:

Del Genio, A.D., and A.B. Wolf, 2000: The temperature dependence of the liquid water path of low clouds in the Southern Great Plains. *J. Climate*, **13**, September issue.

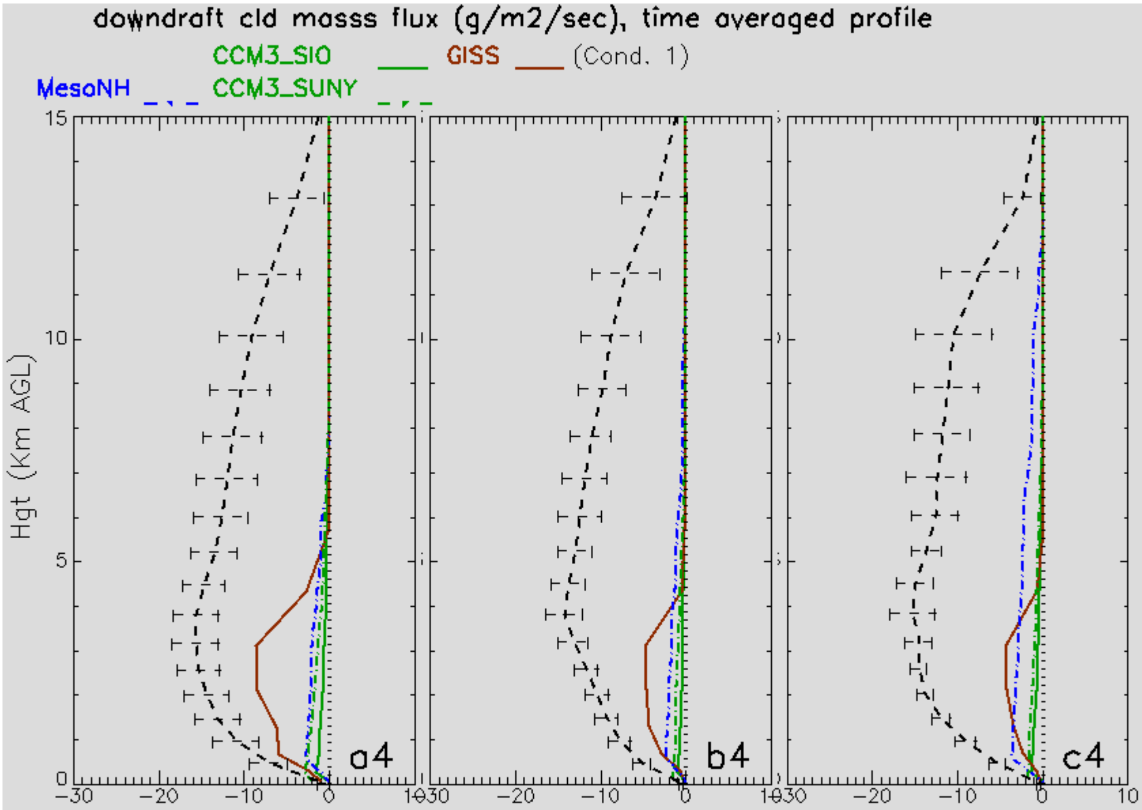
8. Extended abstracts:

Del Genio, A.D., 2000: GCM simulations of cirrus clouds and cloud feedbacks. Proceedings, Workshop on Cloud Processes and Cloud Feedbacks in Large-Scale Models, ECMWF (WCRP-110, WMO/TD-No. 993), 52-61.

9. Status of submitted publications from previous year:

Smith and Del Genio (A simple model of cirrus horizontal inhomogeneity and cloud fraction): Submitted to *Quart. J. Roy. Meteor. Soc.*

Del Genio (GCM simulations of cirrus for climate studies): Cirrus, J.K. Lynch, Ed., Oxford U. Press, in press.



downdraft cld masss flux (g/m2/sec), time averaged profile
CCM3_SIO
GISS
(Cond. 1)
MesoNH
CCM3_SUNY
Hgt (Km AGL)
a4
b4
c4